Gravitational stability in the disk of M51

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1 Abstract

Star formation laws, like i.e. the Schmidt law relating star formation rate and total gas density , have been studied in several spiral galaxies but the underlying physics are not yet well understood.
M51, as a nearby face-on galaxy grand design spiral studied in many line transitions, is an ideal target to study the connection between physical conditions of the gas and star formation activity. In this contribution we combine molecular, atomic, total gas and stellar surface densities and study the gravitational stability of the gas (Schuster et al.2007, Hitschfeld et al. in prep.).
From our IRAM-30m ^{12}CO2-1 map and complementary HI-, Radio Continuum- and ACS B-band-data we derive maps of the total gas density and the stellar surface density to study the gravitational stability of the gas via the Toomre Q parameter. As an important factor in this analysis we also present a map indicating the velocity dispersion of the molecular gas estimated from the equivalent widths $\Delta v_{\rm eq}$ of the ^{12}CO2-1 data.

2 The velocity dispersion of the molecular gas

The velocity dispersion is important for the calculation of the Toomre parameter as it is hindering gravitational collapse. The map of the equivalent widths of ^{12}CO 2–1 $\Delta v_{\rm eq} = \int T dv / T_{\rm pk}$ is shown in Fig.1. It is related to the velocity dispersion via $\sigma_{\rm CO} = \Delta v_{\rm eq}/(2\sqrt{2\,\ln 2})$.
The equivalent widths drop from the center to the outskirts by up to a factor of 5 from less than ~ 20 kms^{-1} to 102 kms^{-1}. The inner spiral arm structure

of M51 in the northern part is much less prominent than in the integrated intensity map (Schuster et al. 2007).

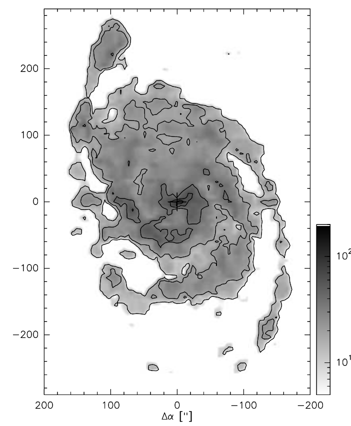

Fig. 1. The map of the equivalent widths of ^{12}CO 2–1 $\Delta v_{\rm eq}$. Contours show 10, 20, 40, 60 to 80 kms^{-1}.

3 The Toomre Q-parameter

The Toomre Q-parameter (Toomre 1964) describes the instability of a differentially rotating, homogeneous thin gas disk against axial symmetric disturbances. It is related to the epicyclic frequency κ, the velocity dispersion of the gas $\sigma_{\rm gas}$ and the total gas surface density $\Sigma_{\rm gas}$ via:

$$Q_{gas} = \frac{\kappa \sigma_{\rm gas}}{\pi G \Sigma_{\rm gas}}. \qquad (1)$$

The epicyclic frequency is determined from the rotation curve of M51, we assume that $\sigma_{\rm gas}$ can be estimated from $\sigma_{\rm CO}$. The surface density $\Sigma_{\rm gas}$ is constructed from complementary VLA-HI data and the ^{12}CO2-1 data as described in Schuster et al. 2007.
As a next step of the stability analysis the stellar component is taken into account (Hitschfeld et al. 2007). The Q-parameter for a pure stellar disk takes the equivalent form as Q_{gas}. The epicyclic frequency determined from the rotation curve is identical. A good approximation for an combined Q-parameter (Wang&Silk 1994) is:

$$Q_{total}^{-1} = Q_{gas}^{-1} + Q_*^{-1}. \qquad (2)$$

To calculate Q_* we obtained the HST-ACS B-band image of Mutchler et al. (2005) and converted it to a stellar mass surface density assuming a constant

mass-to-luminosity ratio $M_*/L_B = 1.54$ (Shetty et al. 2006).
The stellar velocity dispersion is significantly larger than the gas velocity dispersion and can be estimated using an exponential fall-off (Botema et al. 1993) depending on the stellar scale height of the disk.

3.1 Results

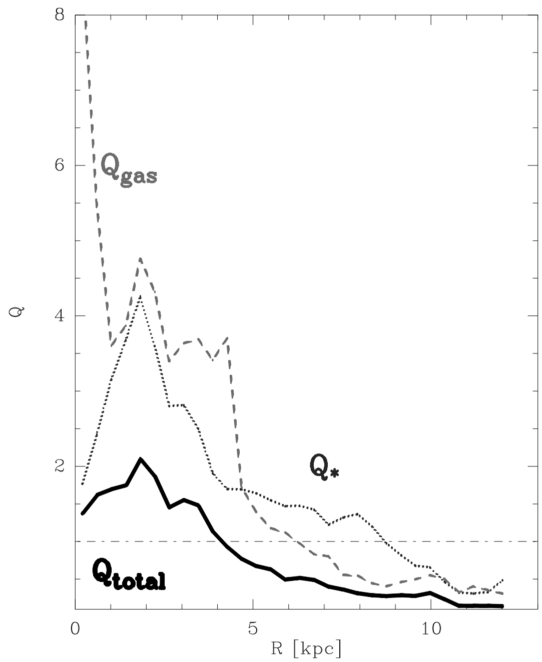

Fig. 2. Radial averages of the Toomre Q-parameter for the total gas Q_{gas}, stellar component Q_* and the total Q_{total}. All parameters have been calculated from inclination corrected quantities. A horizontal line delineates Q=1 for critically stable conditions.

The radial averages of Q$_*$,Q$_{gas}$ and Q$_{total}$ summed in elliptical annulli of 10" are presented in Fig.2. The importance of the stellar contribution is evident and lowers the Q-parameter by up to 50%. Due to the stars the inner part is significantly closer to gravitational collapse than estimations from the gas-only analysis would predict. The gravitational collapse and formation of Giant Molecular Clouds is thus possible and predicted over large regions of the disk. This agrees with previous studies by Boissier et al.(2003) of radial averages of the Toomre Q-parameter in their sample of galaxies comparing the gas-only Q_{gas} and Q_{total}.
The map of the combined Q-parameter is shown in Fig.3. The total Q ex-

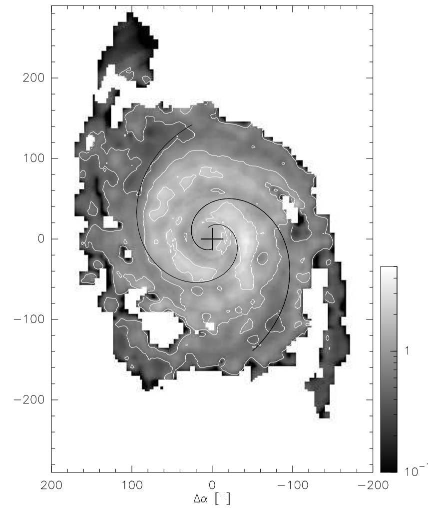

Fig. 3. Map of the combined Toomre-parameter of the stellar and gaseous component Q_{total}. In black two logarithmic spirals indicate the position of the inner spiral arms.

ceeds 1 in the inner interarm regions and drops to beeing critical to collapse ($Q \leq 1$) in the spiral arms indicated by the two black logarithmic spirals. From galactocentric radii of around 4 kpc and beyond Q drops below 1 indicating gravitational instability. Note that the Q parameter in the neighbour galaxy NGC5195 is significantly underestimated due to the exponential decline assumed for the velocity dispersion of the stars.
Star formation is observed over large scales in the disk of M51 and in particular massive, young stars are found in the inner part and especially in the spiral arms. Since not only gravitational stability governs star formation but also mechanism like i.e. spiral density waves and more locally turbulence and supernovae explosions, the Toomre criterion naturally fails to explain the exact location of stars. It is important as a threshold and necessary pre-condition for star formation.

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